WBS 6.8
Trigger

Elliot Lipeles
Trigger L2 Manager
University of Pennsylvania

U.S. ATLAS HL-LHC Conceptual Design Review
Management Session
Arlington, VA
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Biography

- Elliot Lipeles
  - Associate Professor at University of Pennsylvania
  - Lead ATLAS Trigger “menu” group from (2012-2013)
    - menu = list of threshold used
    - a key step in the performance requirements
  - Long-term activity in ATLAS Trigger architecture
    - One of initial advocates planned system architecture
    - Editor of architecture chapter of ATLAS internal review of the initial design
  - Actively involved in simulation of HL-LHC trigger system
  - ATLAS Trigger Rate group leader 2008-2014
  - Analysis Higgs to WW, Higgs to Invisible, Standard Model Dibosons, SUSY trileptons, SUSY stop squark
  - Other experience: CMS DAQ/HLT installation coordination, CDF Offline computing farm management, CLEO DAQ hardware and data-handling and control software

Outline

- Trigger Intro (people, groups,…)
- Physics Requirements and Flow down to performance and technical requirements
- Scope of ATLAS HL-LHC Trigger Upgrade
- Scope of NSF supported Deliverables
- Interaction with International ATLAS
- Determination of Scope and Cost
- Schedule, Dependencies, Risks…
- Budget and Scope Contingency
- Closing Remarks + List of BoEs

Trigger System Overview

- The Trigger system is an online data selection system
  - Reduces data to be readout to a technically feasible volume
    - 40 MHz beam crossing rate to planned 400 kHz readout rate
    - For the 5 MB raw event size, that means a reduction from 200 TB/s to 2 TB/s
  - Reduces data volume to be stored for offline analysis
    - 400 kHz (200 PB/day) readout rate to 10 kHz (5 PB/day) storage rate
  - The selections implemented in the trigger have a strong role in defining the physics performance of the experiment

- The Trigger and DAQ group in ATLAS comprises 86 institutions from 26 countries

Measurement Goals

- The HL-LHC program is broad
  - Higgs as a tool for discovery
  - Dark matter
  - Exploring the Unknown
  - A representative set of measurements is presented in the PEP document (and in the ATLAS scoping document)

Higgs + Unknown

Dark Matter + Unknown

Higgs + Unknown

Channel	Example Quantity	Run 1 Result ($25\ fb^{-1}$)	Target HL-LHC Sensitivity ($3000\ fb^{-1}$)
$H \rightarrow 4\mu$	Relative uncertainty on production	22%	2.2%
VBF $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$	Relative uncertainty on production	360%	17% (7.6σ)
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	Relative uncertainty on production	36% (3σ)	14% (8.0σ)
VBS ssWW	Relative uncertainty on production	34% (3.6σ)	5.9% (11σ)
SUSY $\chi_1^{\pm}\chi_2^{0} \rightarrow \ell bb + X$	Chargino/neutralino mass	>250 GeV (95% CL)	850 GeV (5σ observation)
$HH \rightarrow 4b$	K-K graviton production	---	4.4σ (at M = 2 TeV)

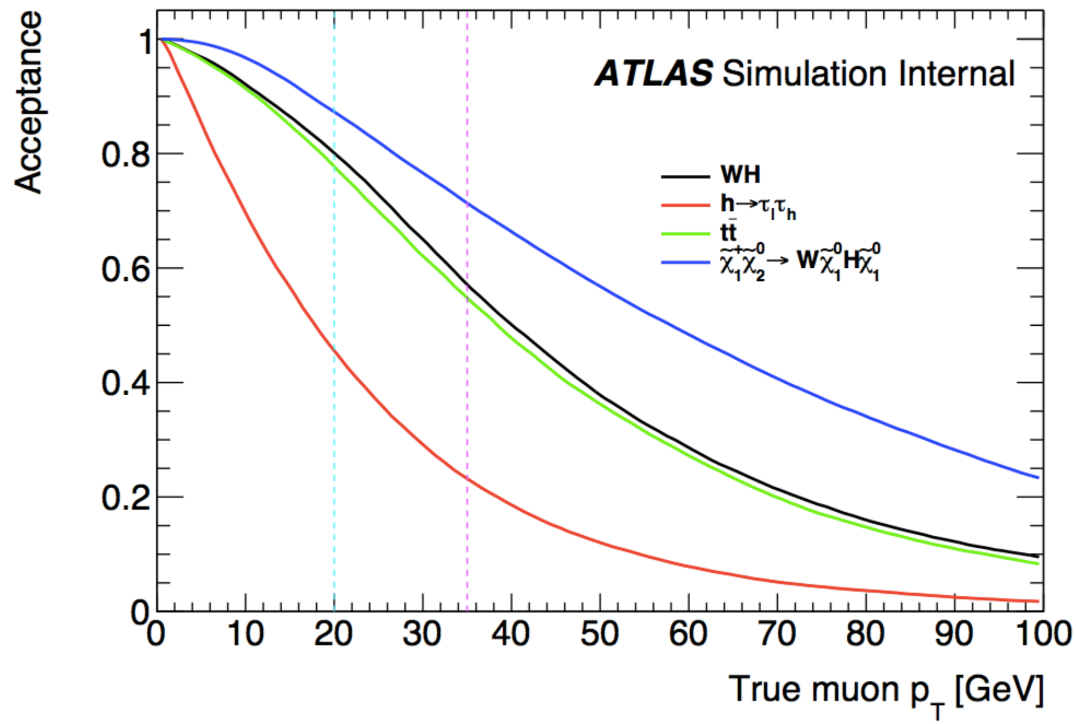
Trigger Flow Down

ATLAS System Design

SCIENCE GOALS	SCIENCE REQUIREMENTS	NSF SCOPE
$H \rightarrow 4\mu$ (2.2%) VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb+X$ (850 GeV)	Muon Trigger • single μ p_T threshold ~ 20 GeV • geometric accept: 95% (barrel)	• Muon Electronics • Tile Electronics • sMDT • L0Muon
VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb+X$ (850 GeV)	Electron Trigger • single e p_T threshold ~ 22 GeV	• LAr+Tile Electronics • L1Global • L1Track/FTK++
$HH \rightarrow 4b$ (4.4σ KK Graviton)	Jet Triggers • 4-jet E_T threshold ~ 75 GeV • “fat” jet threshold ~ 375 GeV • jet-vertex confirmation at L1	• Lar+Tile Electronics • L1Global • L1Track/FTK++
Compressed SUSY ($\chi_1^\pm \chi_2^0$)	Missing E_T Trigger • ME_T threshold ~ 200 GeV • track-based ME_T correction	• L1Global • L1Track/FTK++

Threshold Requirements

- **Guideline:** Keep as many events that show evidence of weak scale physics (weak scale = masses of W, Z, and Higgs bosons
- Single electron or muon triggers at ~20 GeV
  - Maintain good acceptance for leptons from W and Z bosons
  - Even more important if physics target favors taus



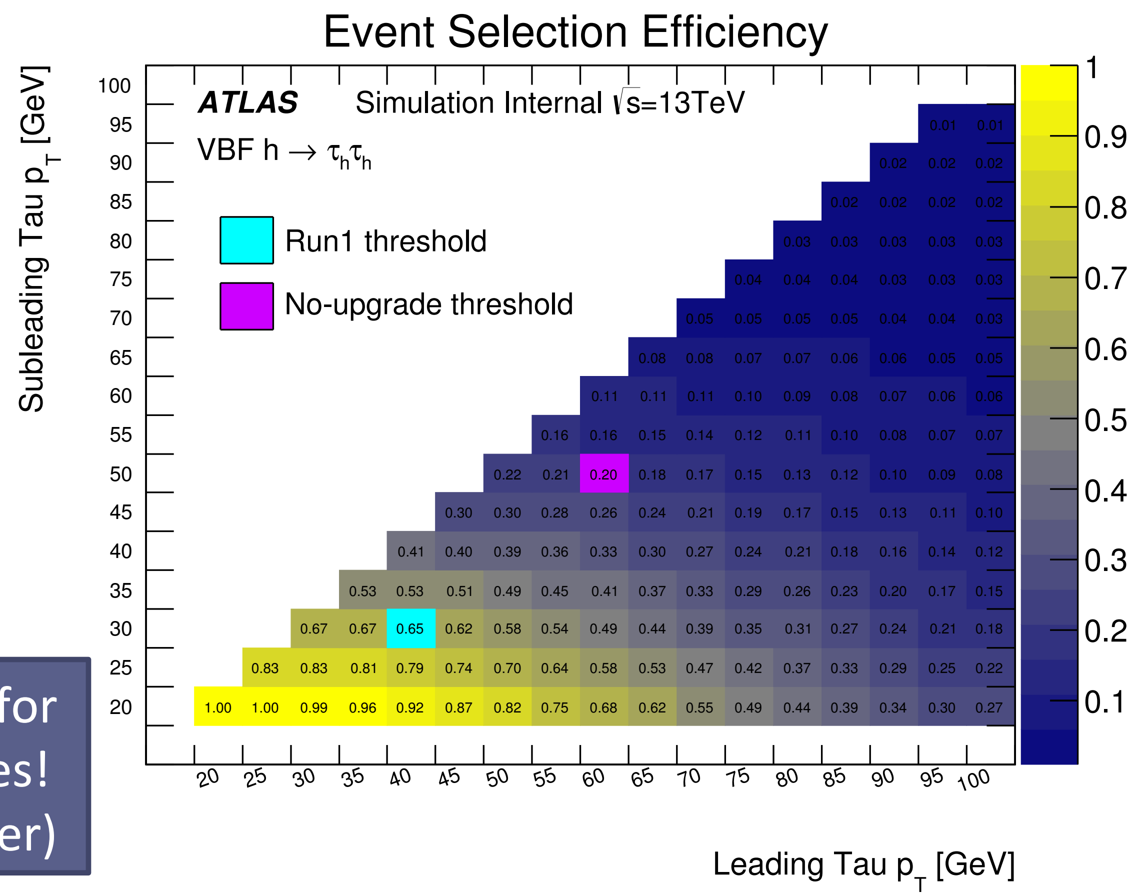
Upgrade acceptance gain: 25% for WχHχ , 40% for tt and WH, 75% for H→ττ

Note: Acceptance gain translates to gain in effective running time

Threshold Requirements

- **Guideline:** Keep as many events that show evidence of weak scale physics (weak scale = masses of W, Z, and Higgs bosons

- Di-tau Events
  - Important for many physics channel:
    - H → ττ
    - Standard model HH → bbττ
  - SUSY can favor tau in final state

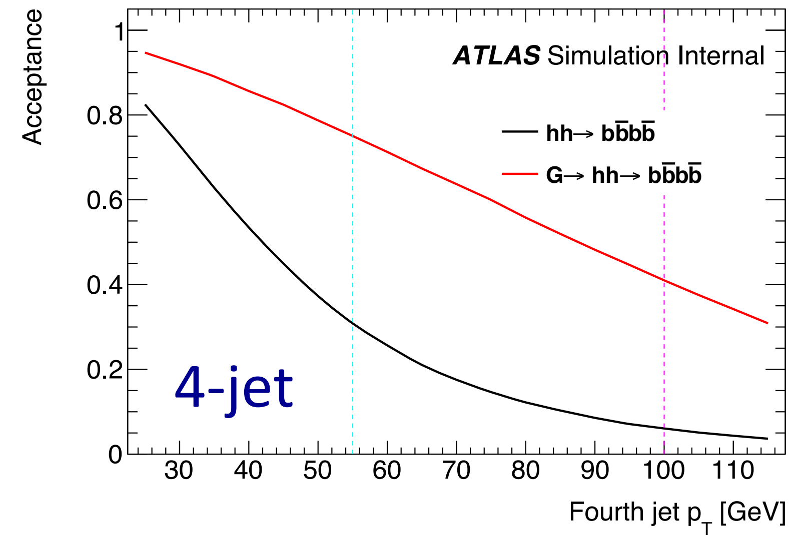


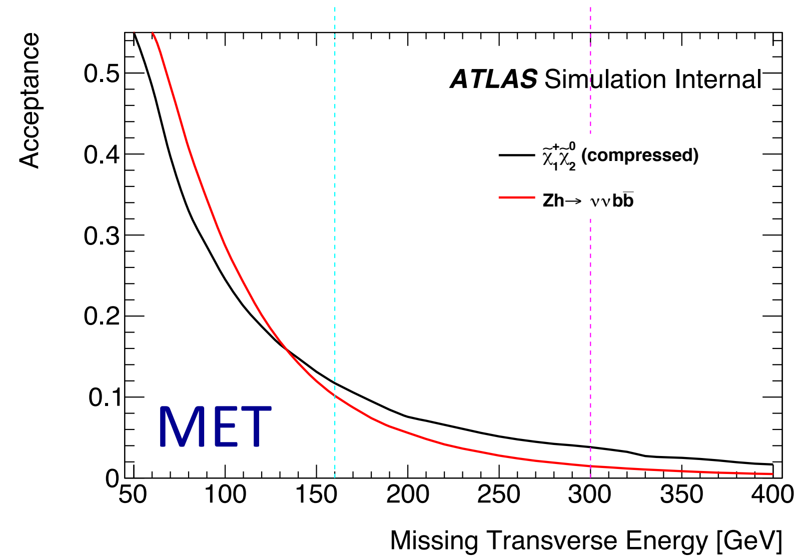
Upgrade acceptance gain for H → ττ a factor of 3.3 times! (similar for dileptons trigger)

Threshold Requirements

- **Guideline:** Keep as many events that show evidence of weak scale physics (weak scale = masses of W, Z, and Higgs bosons
- 4-jet events
  - HH → 4b (SM or BSM)
  - Diboson searches (= Unknown)
- MET
  - Important for SUSY and Dark Matter
  - ZH→ννbb

Upgrade acceptance gain
MET: ZH

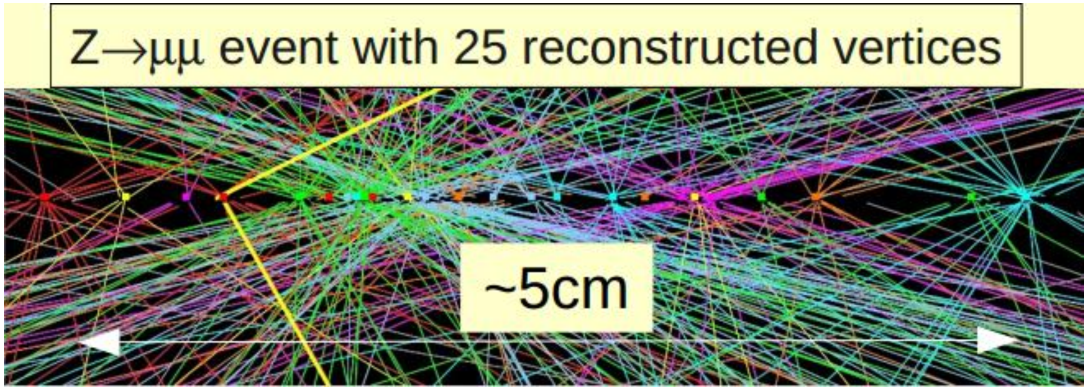




Threshold Requirements

Pile-up and hadronic objects (jets & MET)

- Pile-up is the number of collisions per beam crossing
  - Run 1 pile-up ~ 20
  - HL-LHC pile-up ~200

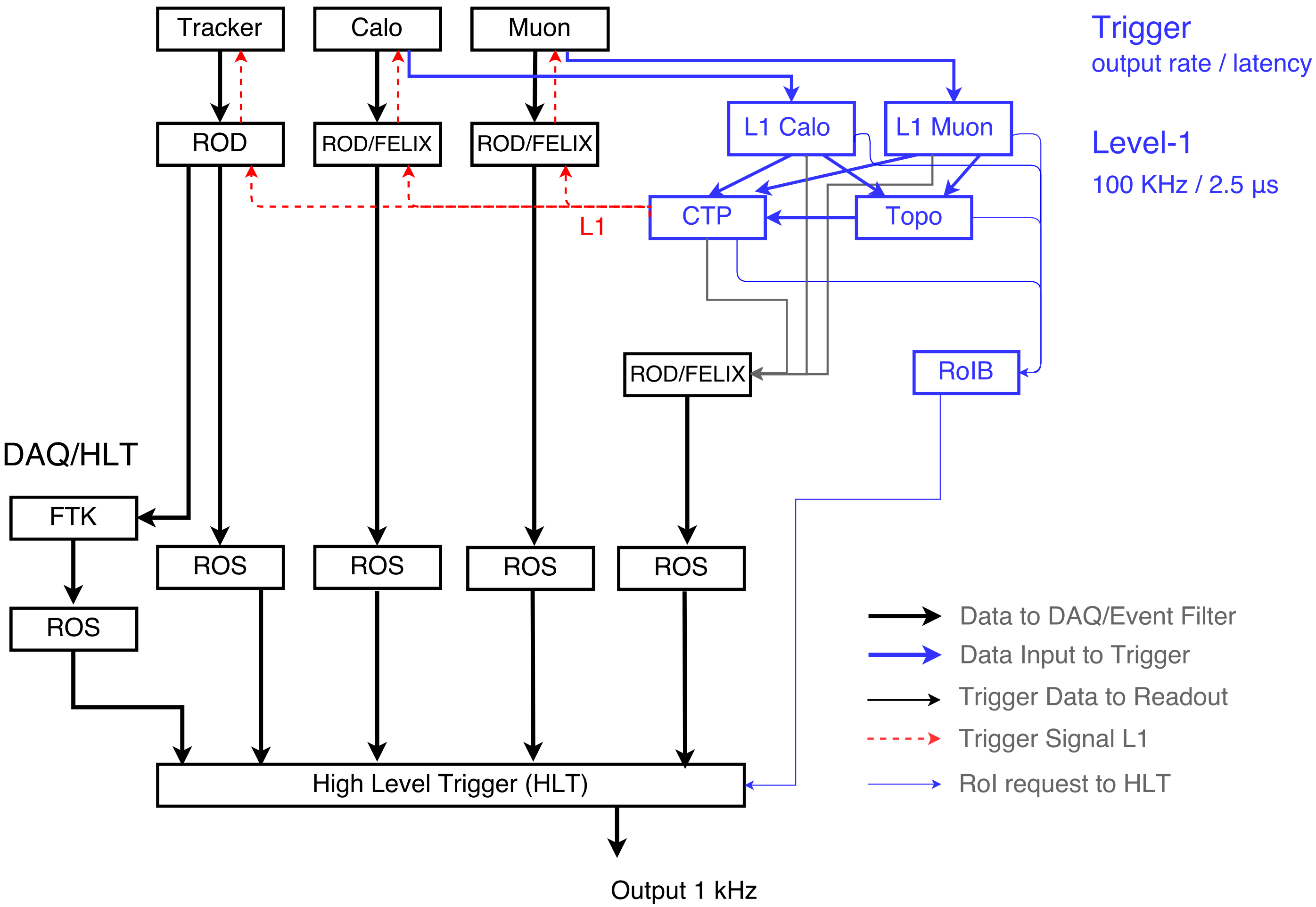


Tracking is the main tool for differentiating from which vertex something came
- Tracks are critical in b-jet identification

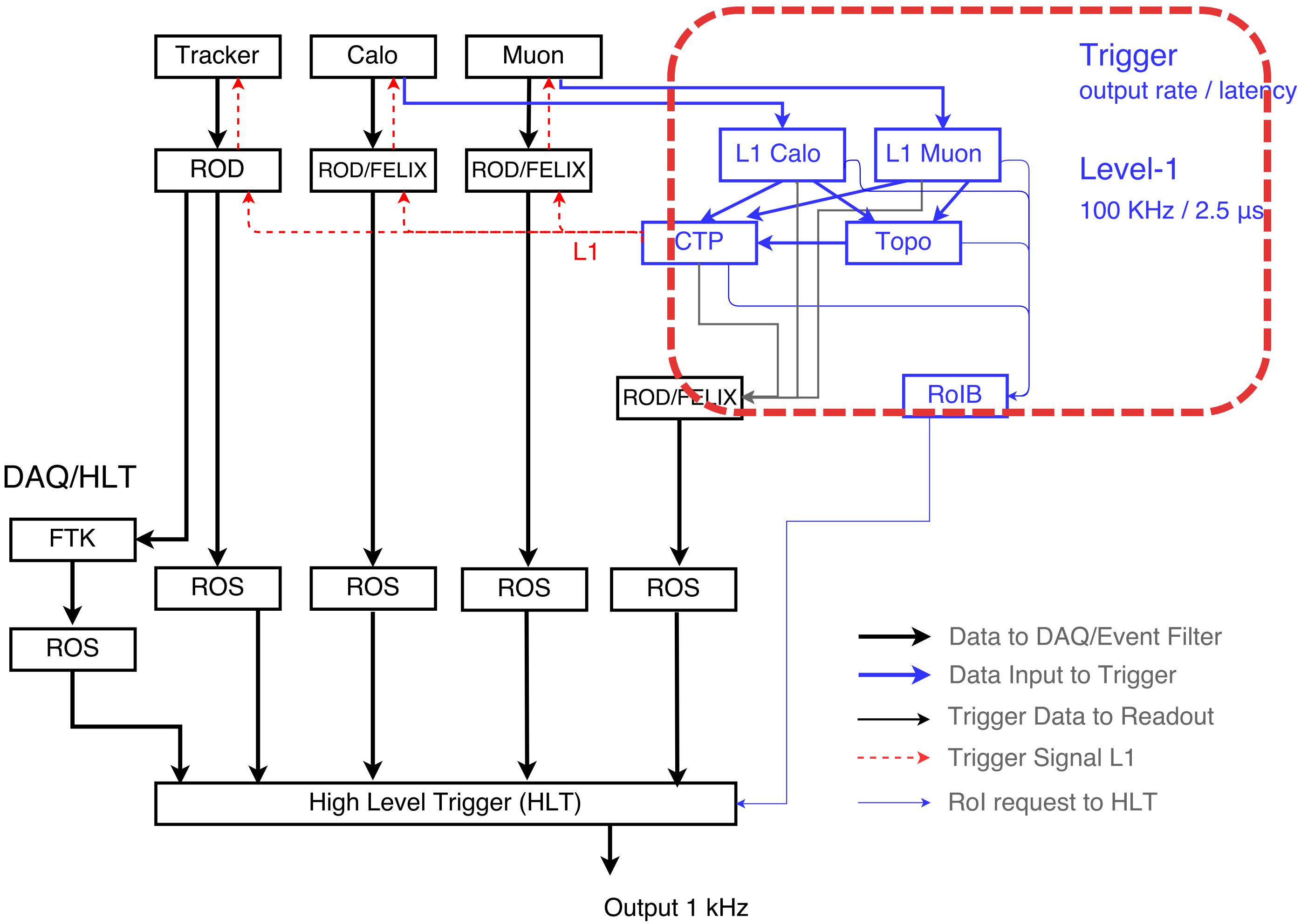
Tracks are increasingly being used for pile-up suppression in jet & MET
- Run 2 jets used track-based jet energy corrections
  - Most 4-jet events at HL-LHC at the trigger threshold will be from pile-up
- Run 2 MET uses tracking to decide which jets come from the vertex of interest
- Implementation of these for Run 2 is limited by the tracking CPU in the HLT

So for online hadronic objects to be compatible with offline with reasonably sharp turn-on curves, tracking is needed as early as possible and as complete as possible

Phase-1 System



Phase-1 System



1 hardware trigger level

- 100 kHz Accept Rate
- 2.5 µs Latency

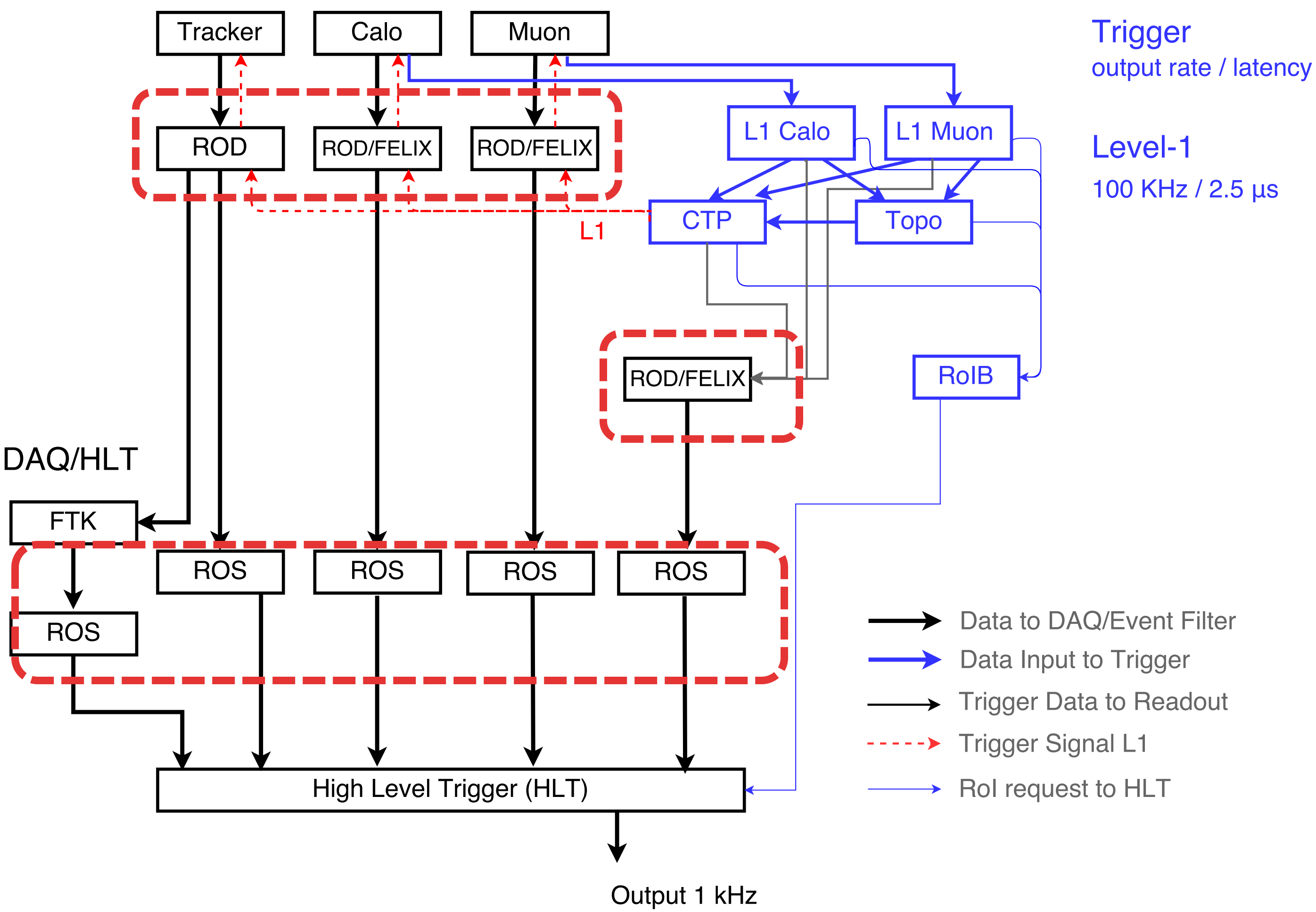
Calo

- Course granularity for e, gamma, and jets
- Added course granularity fat jets and global objects (gFEX)

Muon

- Fast detectors only (RPC and TGC)
- "New small wheel" (NSW) improves fake rejection in endcap

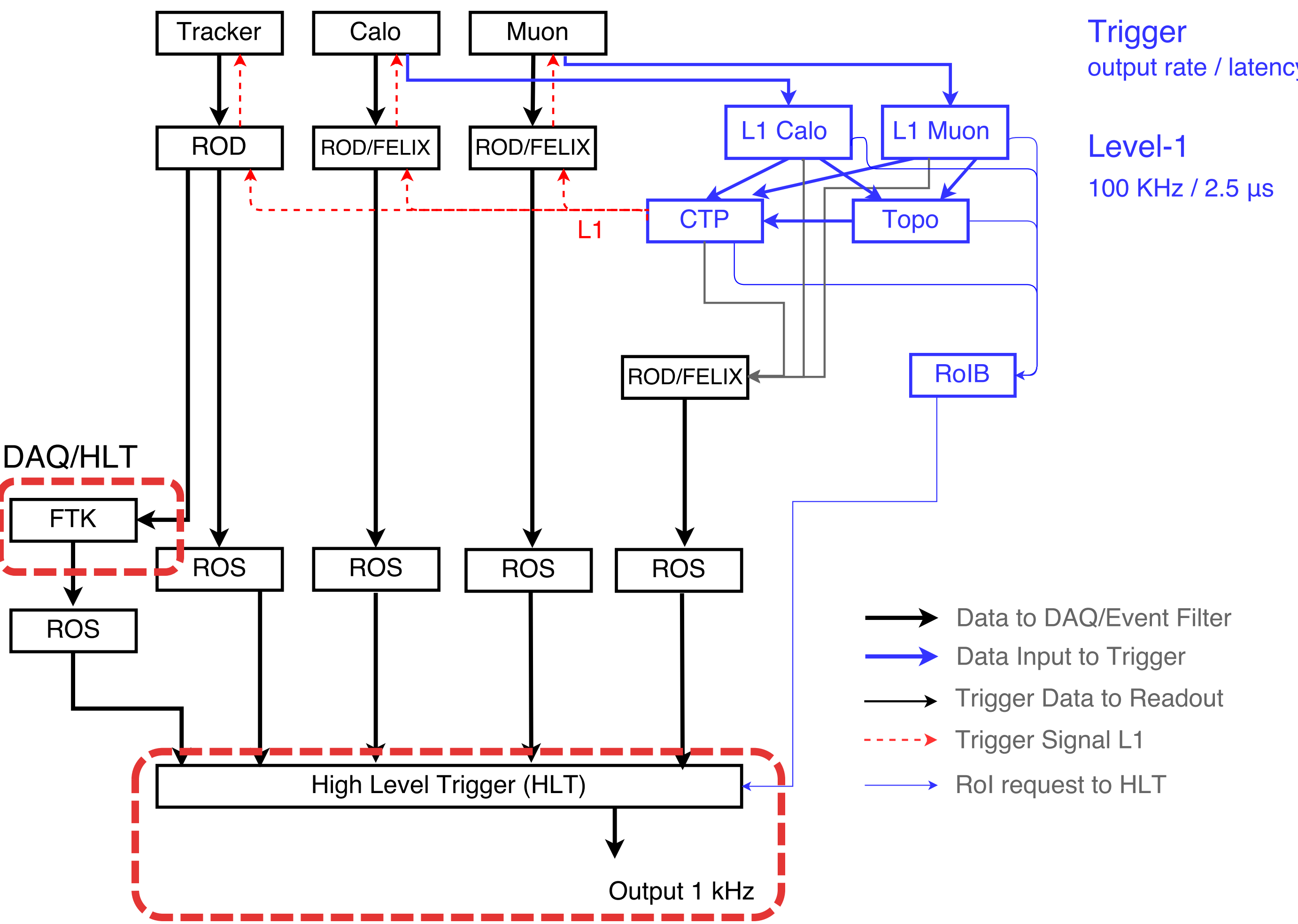
Phase-1 System



Data then readout via DAQ system

- Data aggregated and buffered

Phase-1 System



"High-Level Trigger"

- PC-based farm
- Adds tracking using Hardware preprocessor for track reconstruction (FTK)
- Adds full granularity calorimeter information
- Adds high precision muon chamber (MDT) information
- Output rate 1 kHz

Phase-1 System Limitations

General Physics Goal: Threshold goals similar to Run 1 thresholds

- These thresholds are proven to support a broad physics program

Phase-1 hardware at HL-LHC luminosity for Target Thresholds (~Run1)

Many triggers in excess to 100 KHz (= the Phase-1 limit)

Item	Run 1 Offline p_T Threshold [GeV]	Phase-I Level-1 system performance at $L = 7.5 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ Offline Threshold for Phase-II Goal [GeV]	Level-1 Rate [kHz]
isolated Single e	25	22	200
single μ	25	20	40
di-γ	25	25	8
di-e	17	15	90
di-μ	12	11	10
$e - \mu$	17,6	17,12	8
single τ	100	150	20
di-τ	40,30	40,30	200
single jet	200	180	60
four-jet	55	75	50
E_T^{miss}	120	200	50
jet + E_T^{miss}	150,120	140,125	60

Including key single electron trigger

Would need to raise electron threshold to ~35-40 GeV

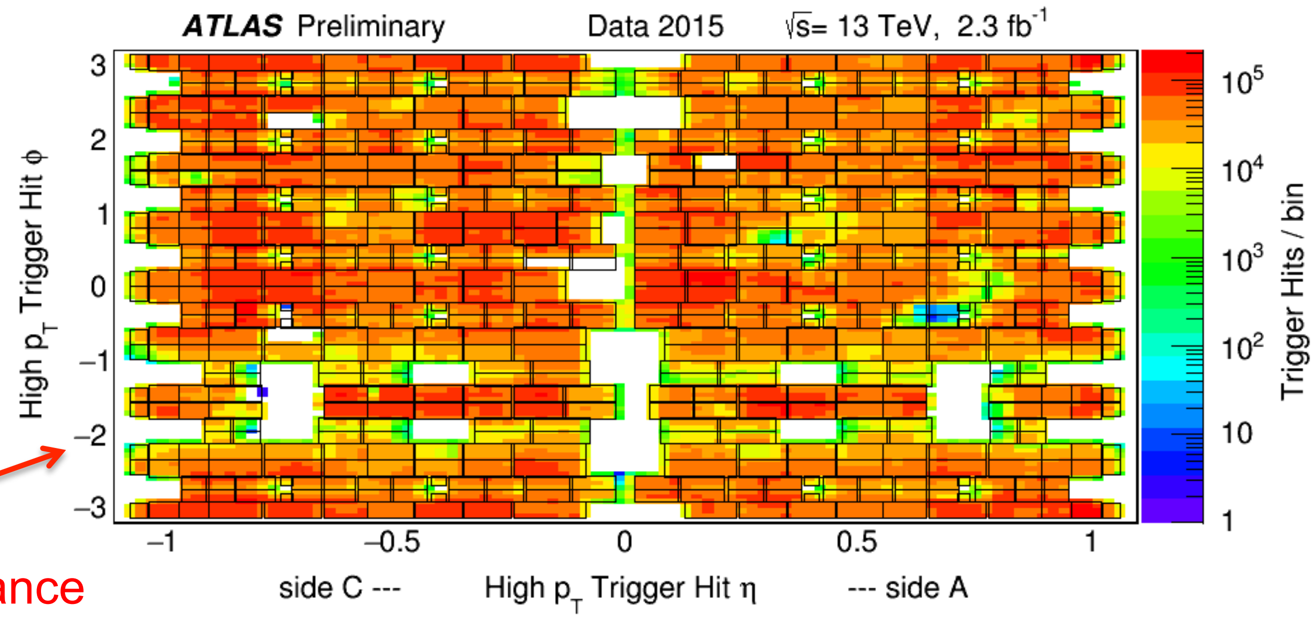
Hadronic triggers allowed to degrade somewhat

Offline thresholds that can be used with the associated trigger

Phase-1 System Limitations

Another Key Issue:

Low muon trigger efficiency of Phase-1 system



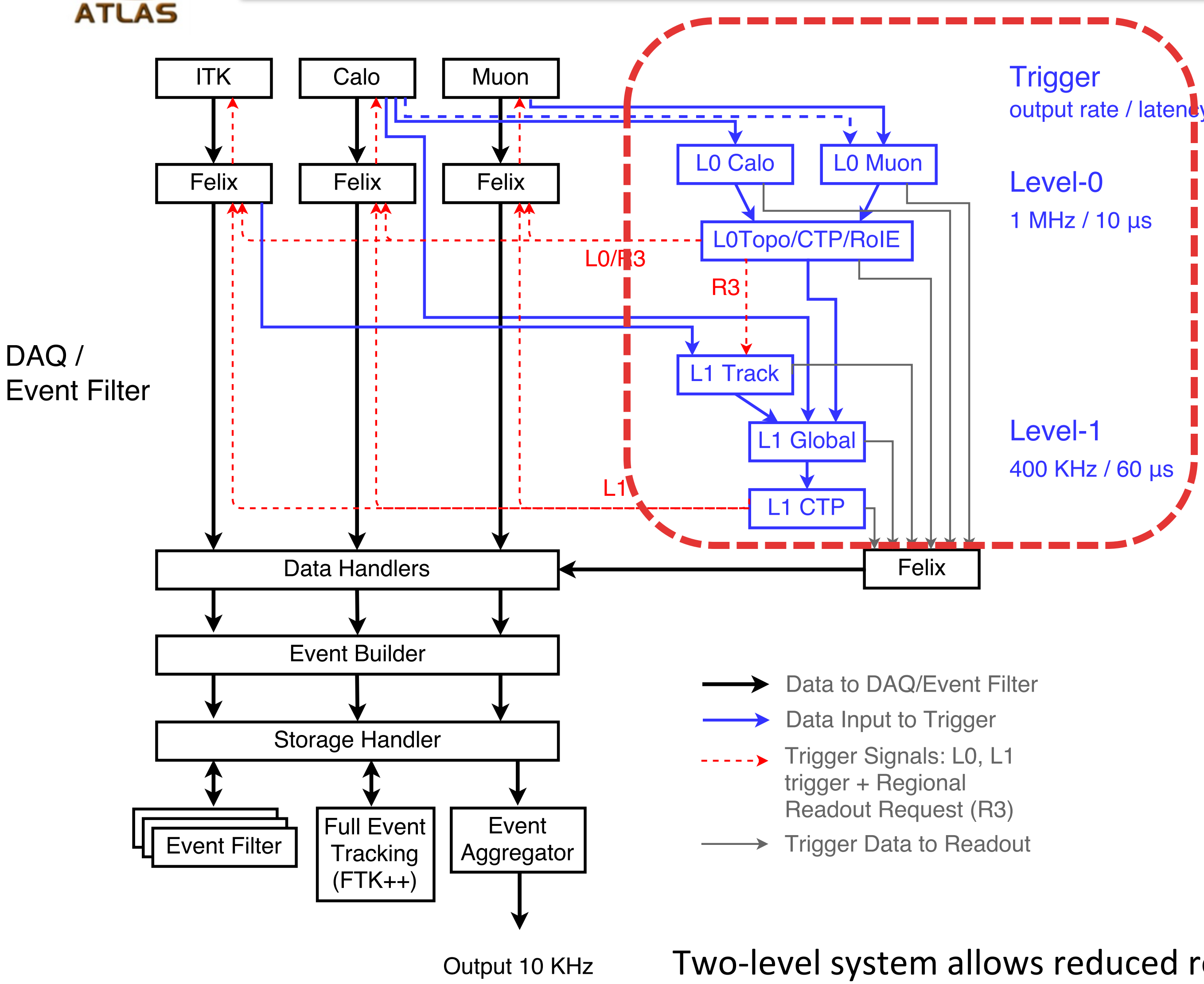
RPC chamber acceptance has lots of holes

Because RPC chamber (barrel) need to be run at reduced voltage to avoid aging, barrel efficiency would be further reduced to 65%.

- Bad for single muon trigger, *really* bad for dimuon triggers

Addressed by a combination of new RPCs and using high precision MDT chambers in trigger which improves the 65% to 95%

System Design



Two hardware trigger levels

Level 0 (L0)

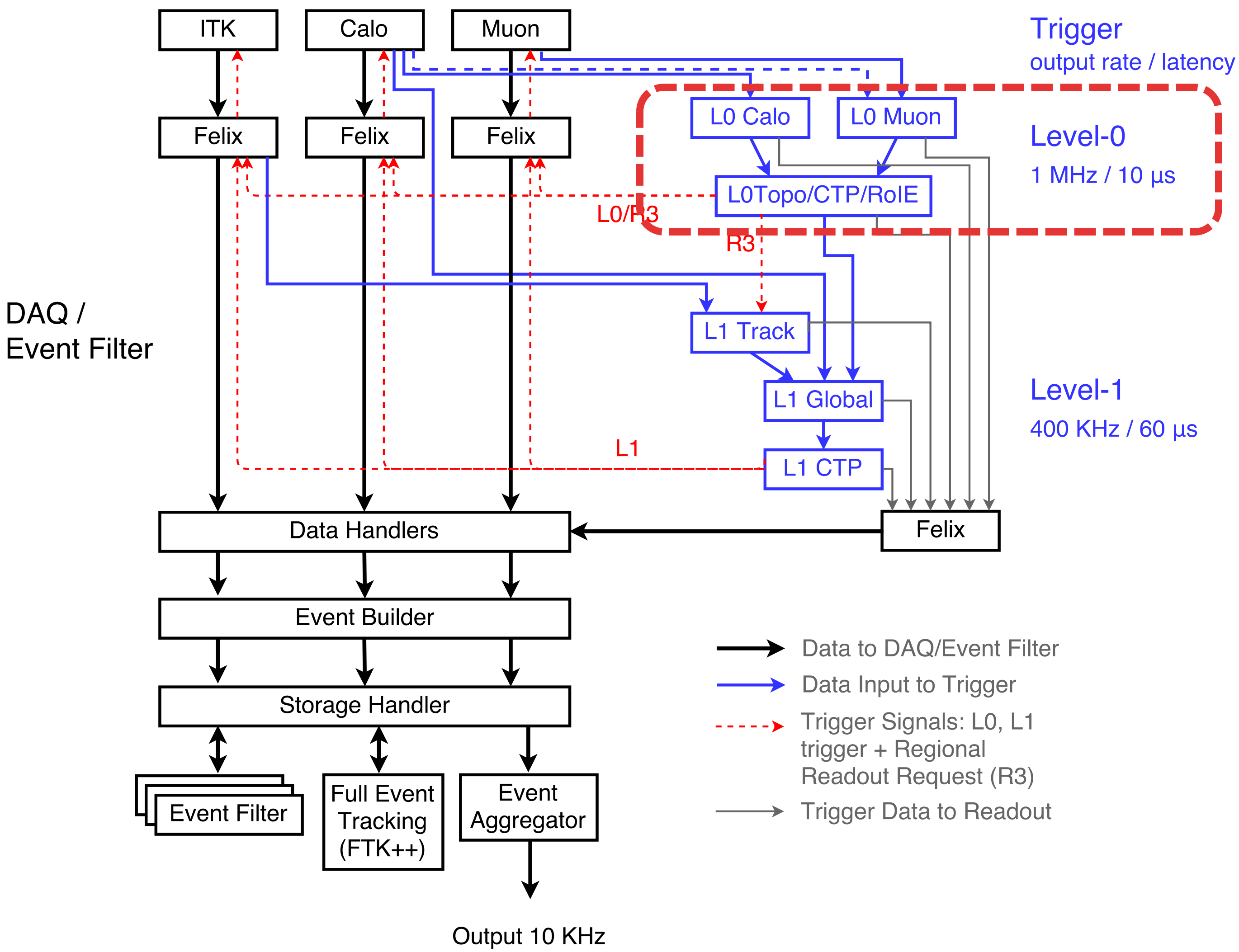
- 1 MHz L0 Accept Rate
- 6/10 µs Latency
- 6 µs = Trigger Target
- 10 µs = Detector Req.
- Difference is a contingency

Level 1 (L1)

- 400 kHz L1 Accept Rate
- 30/60 µs Latency

Two-level system allows reduced readout bandwidth requirements on detectors (compatible with legacy electronics)

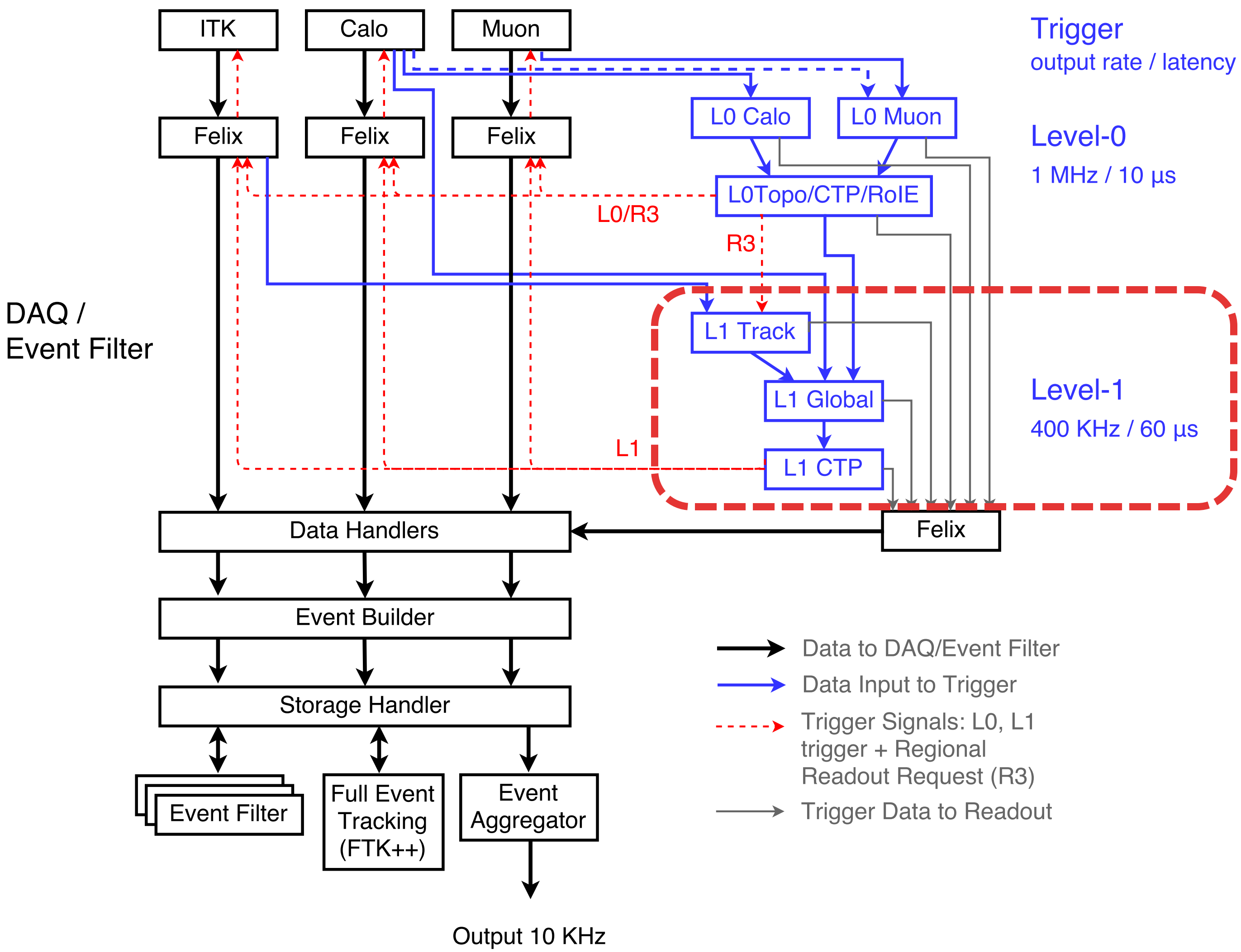
System Design



Level 0 (L0)

- Input 40 MHz
- Output 1 MHz
- Same hardware as Phase-1 L1 trigger
- Extended to have High Precision Muon Chambers (MDT) →improves efficiency
- Higher accept rate (100 kHz → 1 MHz) means higher physics acceptance

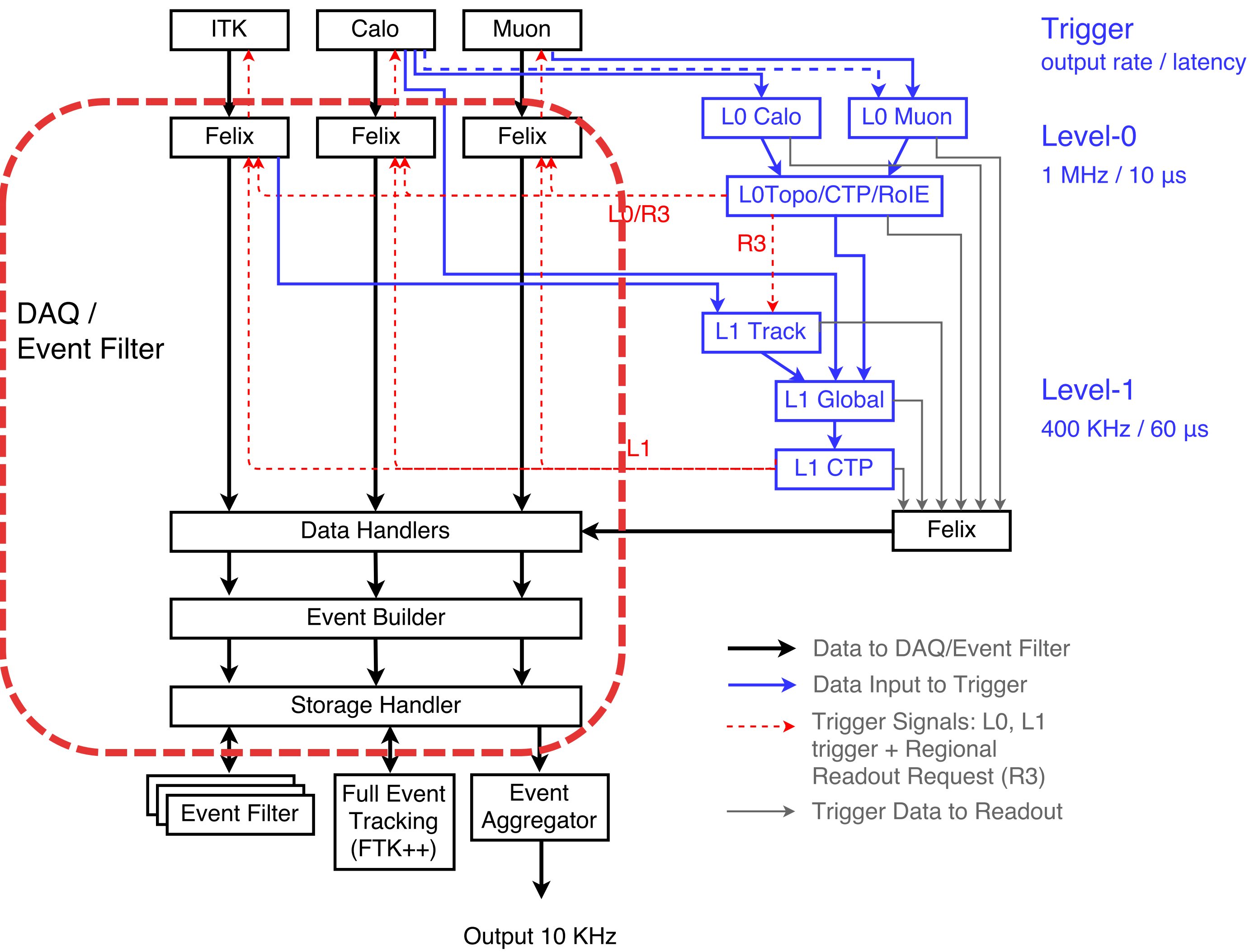
System Design



Level 1 (L1)

- Input 1 MHz
- Output 400 kHz
- Tracking in regions of interest (L1Track)
  - 10% of data at 1 MHz
- Full granularity calorimetry combined with tracking in regions of interest to improves rejection before HLT (L1Global)

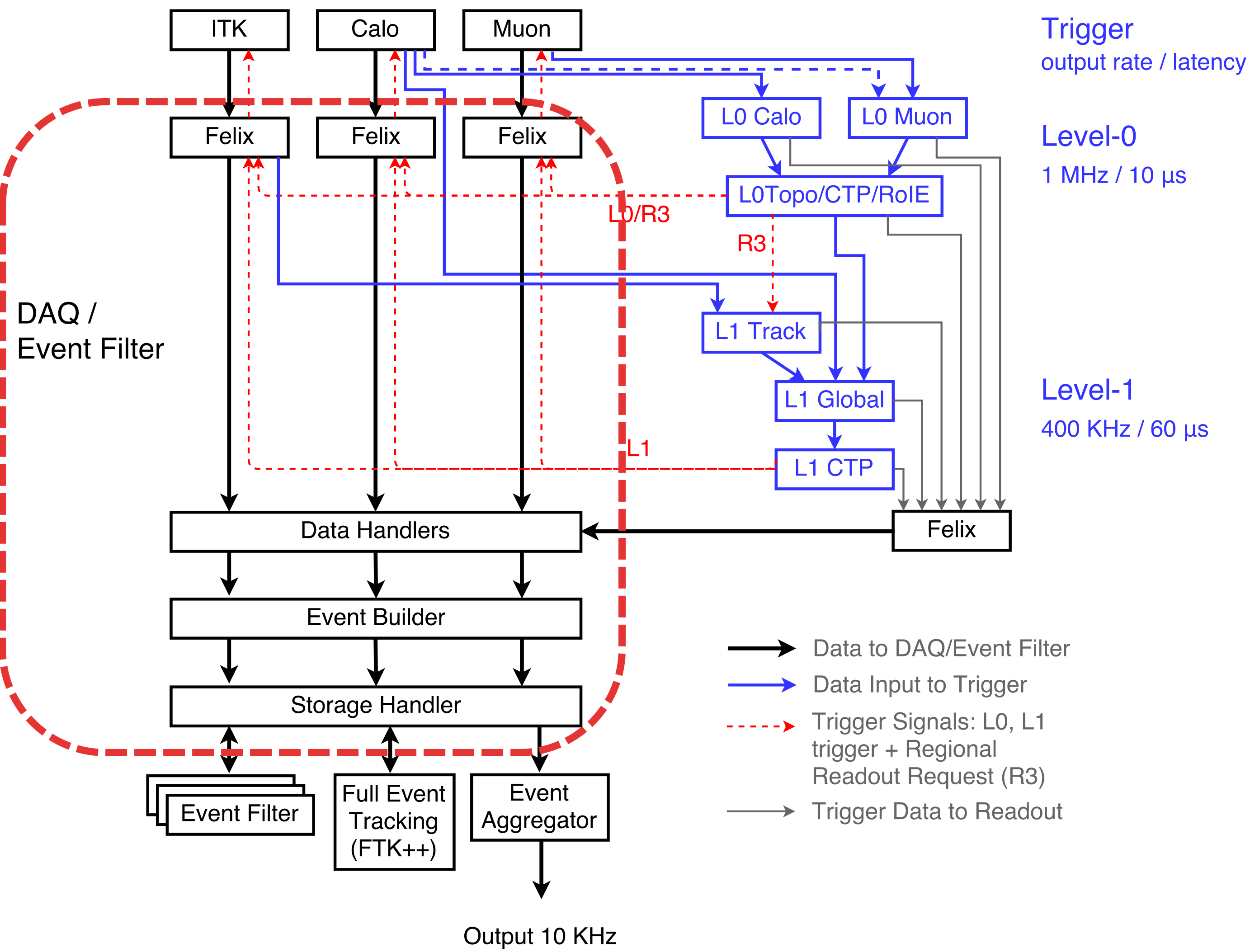
System Design



DAQ System

- Data aggregated and buffered

System Design



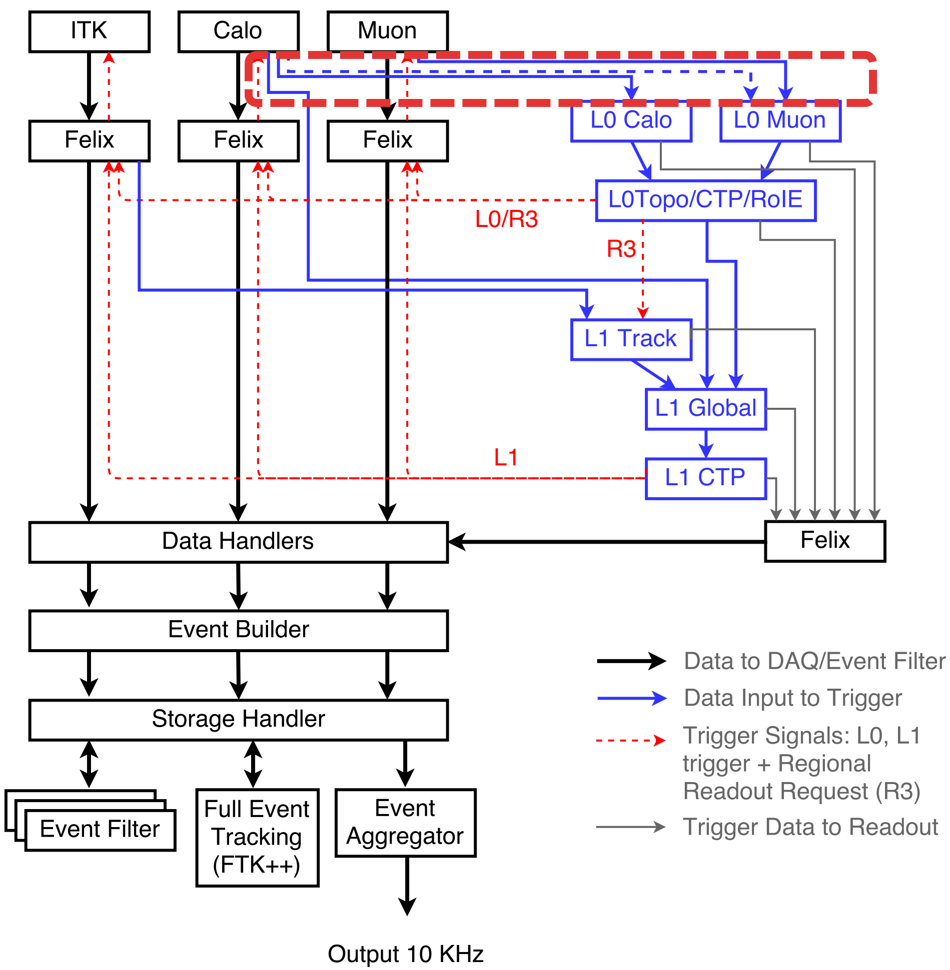
Event Filter System

- Input 400 kHz
- Output 10 kHz
- PC-based farm
- With hardware-based tracking co-processor (FTK++) which provides 100 kHz full-detector tracking
- Offline-like algorithms assure no loss in effective threshold due to incompatibility

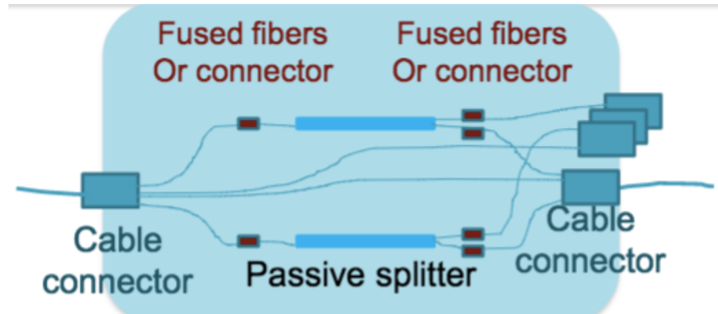
US Involvement

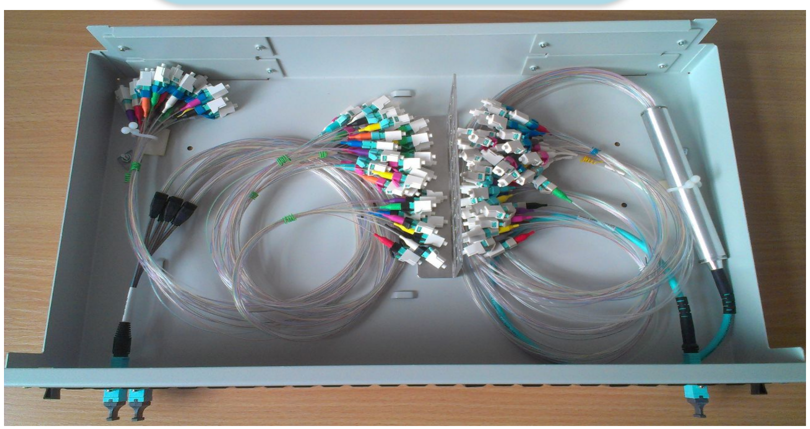
- 17 US institutions in ATLAS Trigger/DAQ group
- US institutions play a key role in the overall management of the ATLAS Trigger/DAQ group
  - David Strom (Oregon) is one of two Trigger/DAQ managers
  - Chris Bee (Stonybrook) is Institute Board Chair
- The US has played a strong role in the trigger hardware for the Phase-1 upgrade
- US institutes involved in HL-LHC construction plan
  - U of California (Irvine)
  - University of Chicago
  - U of Illinois (Urbana-Champaign)
  - Indiana University
  - University of Oregon
  - University of Pennsylvania
  - University of Pittsburgh
  - Louisiana Tech
  - Michigan State University
  - Northern Illinois University
  - Stanford
- Planning for the US/NSF contribution to the trigger system has been discussed with the TDAQ management, but no formal agreements have been made

Proposed NSF Scope

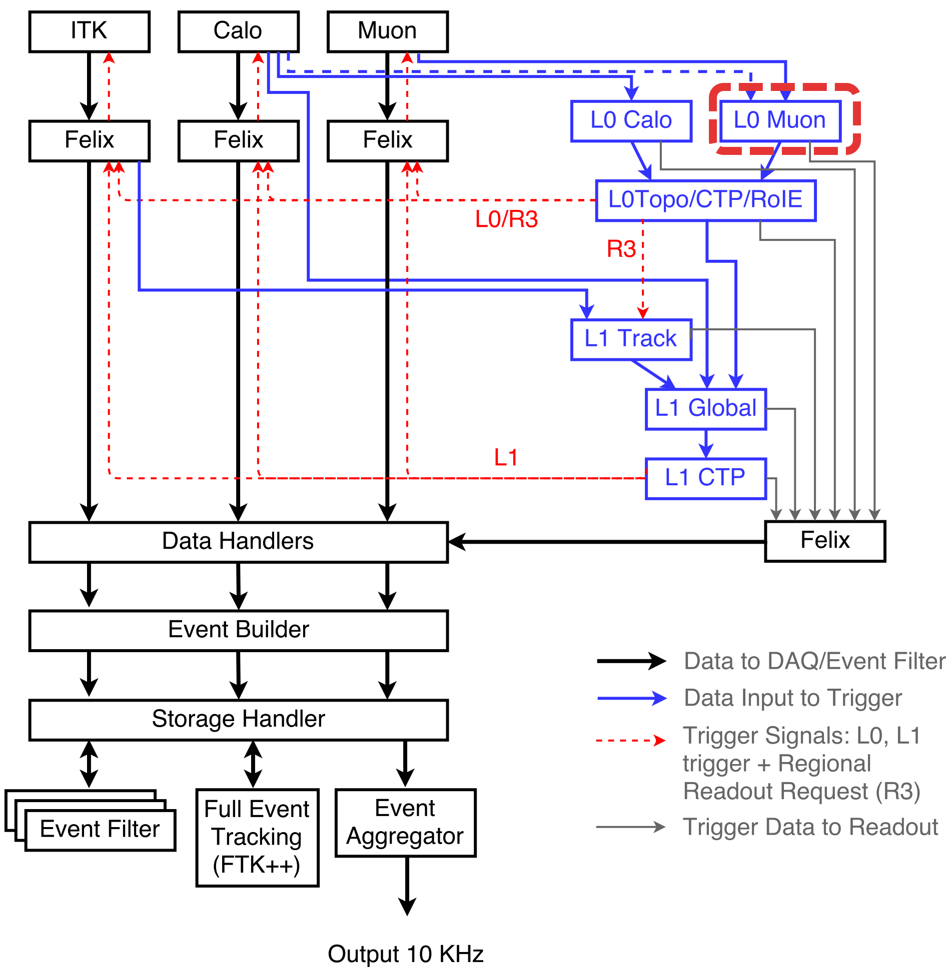


- 6.8.y.1 L0 Calo
  - Rebuild fiber optic input router because of changes to tile inputs
    - Passive optical router maps and splits fiber signals to prep pattern recognition
  - MSU is building Phase-1 system this capitalizes on their unique expertise
  - **Institutes**: Michigan State (MSU)

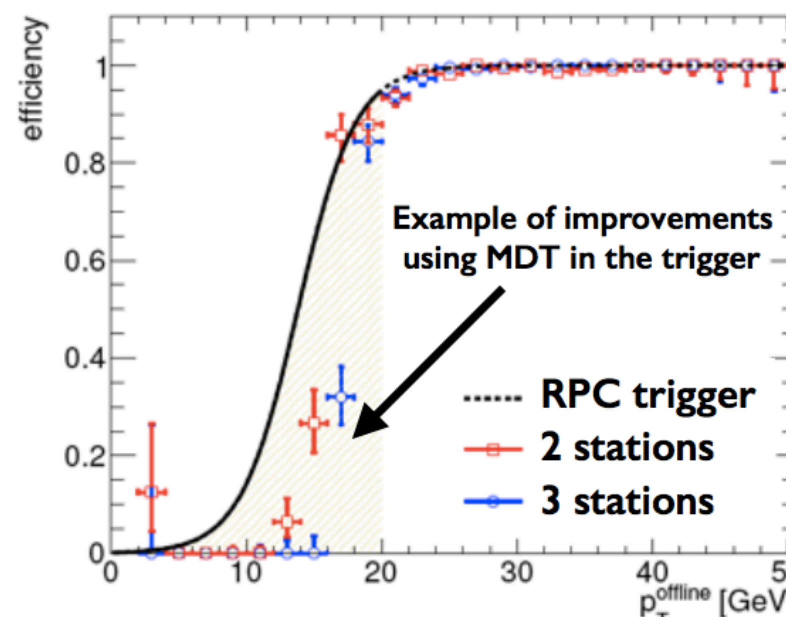




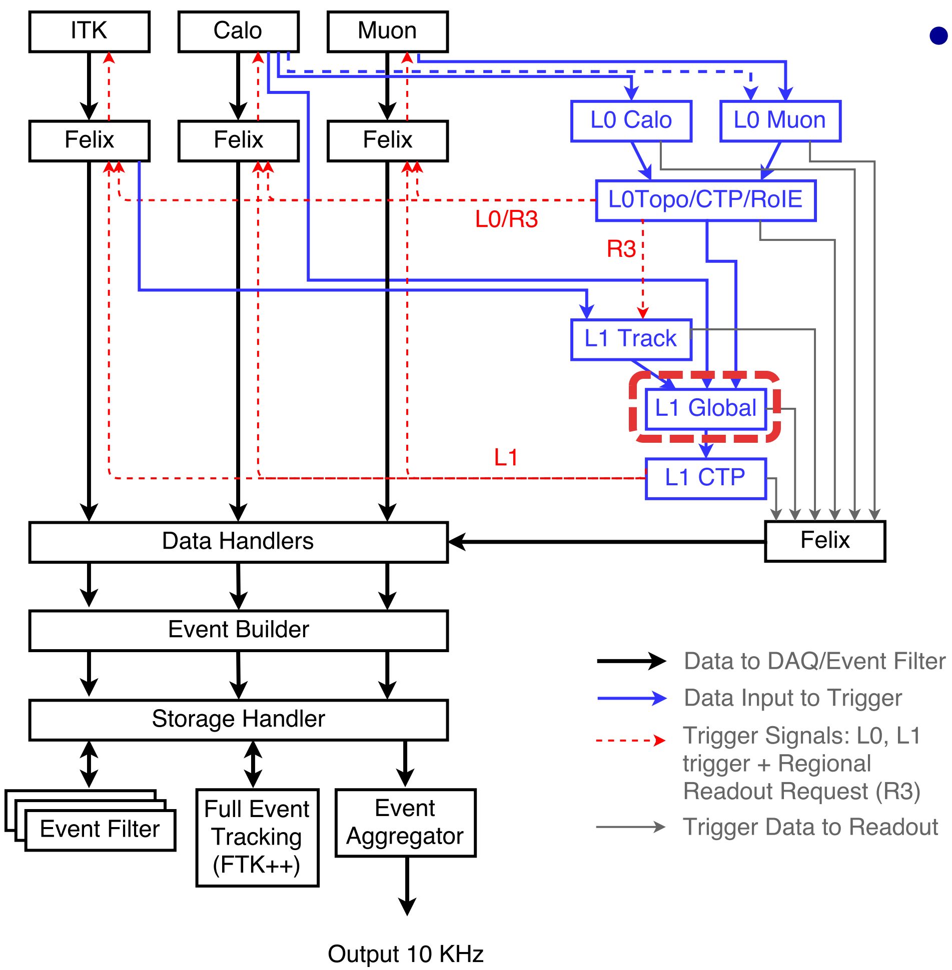
Proposed NSF Scope



- 6.8.y.2 L0 Muon
  - Processing mezzanine boards for MDT (high-precision chambers) trigger with firmware (32 boards)
  - Sharpens muon turn-on curve, reduces rates, improves efficiency
    - Key for high efficiency, low rate single muon trigger
  - **Institutes**: UC Irvine

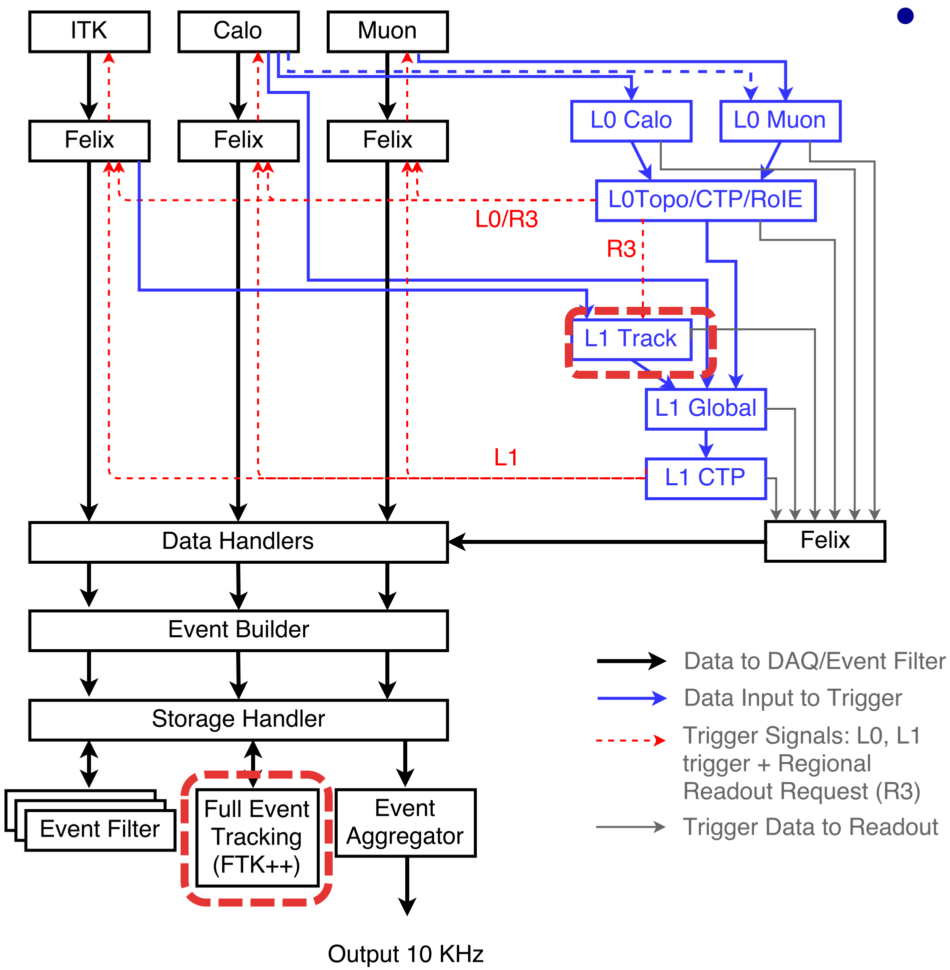


Proposed NSF Scope



- 6.8.y.3 L1 Global Processing
  - L1 Global algorithms are where the rate reduction from 1 MHz to 400 KHz happens
  - 4 firmware algorithms focus on hadronic triggering:
    - Offline-like energy clustering
    - Offline-like Jet construction
    - Global quantities (MET, HT)
    - Track-based pile-up rejection
  - This builds on US experience with Phase-1 “gFEX” system which does global hadronic triggering in what will be L0
  - **Institutes**: U Chicago, U Indiana, Louisiana Tech, Michigan State, U Oregon, U Pittsburgh

Proposed NSF Scope



- 6.8.y.4 L1Track/FTK++ Processing
  - L1Track provides regional tracking at 1 MHz at low-latency as input to L1 Global
    - Many many uses… key for electron, tau, and multiobject hadronic triggers
  - FTK++ provides full detector tracking to be used in the Event Filter (PC farm)
    - This is expected to be critical for maintaining sharp turn-on curves for offline definitions of jets and MET that involve tracking and also for maintaining low pT thresholds for multi b-jet triggers
  - 690 mainboards (data preparation) and 1104 track-fitting mezzanines with firmware
  - Capitalizes on US experience on the Phase-1 FTK system
  - **Institutes**: U Chicago, U Illinois Urbana-Champlain, U Indiana, Northern Illinois University, U Penn, Stanford,

NSF Scope Definition

- Scope defined in the context of US expertise and physucs interests

- 6.8.y.1 L0 Calo
  - Institutes: Michigan State University (MSU)
  - MSU Building very similar system for Phase-1
- 6.8.y.2 L0 Muon
  - Institutes: UC Irvine
  - Experience with muon readout electronics
- 6.8.y.3 L1 Global Processing
  - Institutes: Chicago, Indiana, Oregon, Pitt, LTU, MSU,
  - US involvement in Phase-1 gFEX hardware and firmware
- 6.8.y.4 L1Track/FTK++
  - Phase-1 FTK project is has substantial (~50%) US contribution

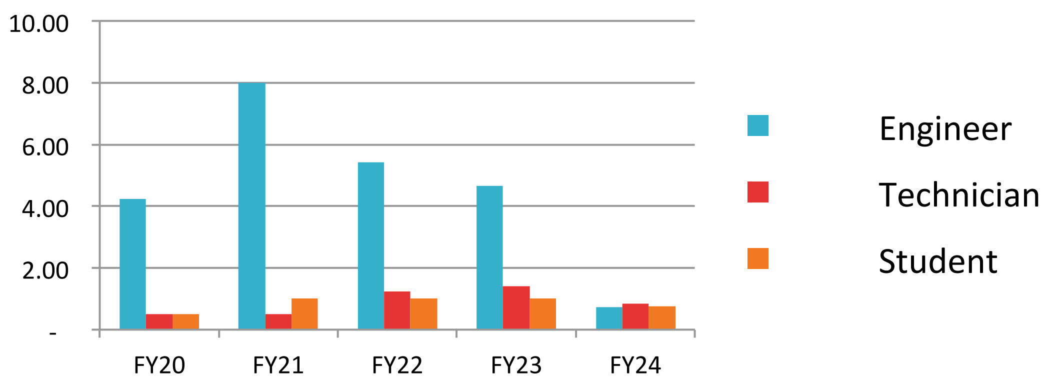
Cost and Effort Estimates

- Cost, Effort, and Schedule estimates are based on
  - Analogy to Phase-1 system
  - Scaled based on estimates of the HL-LHC input data volumes
    - And in some cases, more detailed studies within ATLAS of needs
- Details
  - 6.8.y.1 L0 Calo
    - Based on Phase-1 fiber plant
  - 6.8.y.2 L0 Muon
    - MDT mezzanine based on experience with Phase-1 NSW and expert opinion using one possible system configuration
  - 6.8.y.3 L1 Global Processing
    - Per algorithm effort based on Phase-1 gFEX algorithm work
    - Scaled based on number of algorithms and expert opinion for differences
  - 6.8.y.4 L1Track/FTK++
    - Based on FTK experience
    - Scaled by numerical estimates of the data volume and number of patterns needs using ATLAS work from scoping document

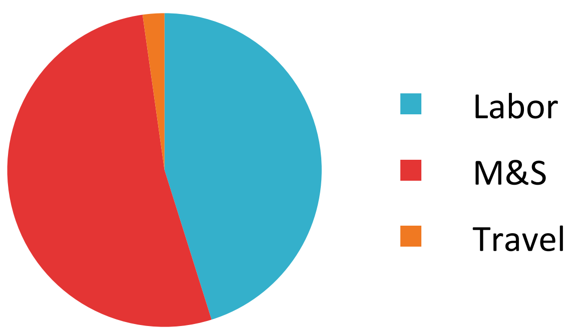
Budget

6.8 Trigger NSF Total Cost (AYk$)						
	FY20	FY21	FY22	FY23	FY24	Grand Total
NSF						
Labor	958	1,786	1,371	1,288	322	5,725
M&S	207	96	753	5,606	9	6,670
Travel	32	61	91	86	12	283
NSF Total	**1,197**	**1,943**	**2,215**	**6,980**	**343**	**12,678**

WBS 6.8 Trigger NSF Labor Types

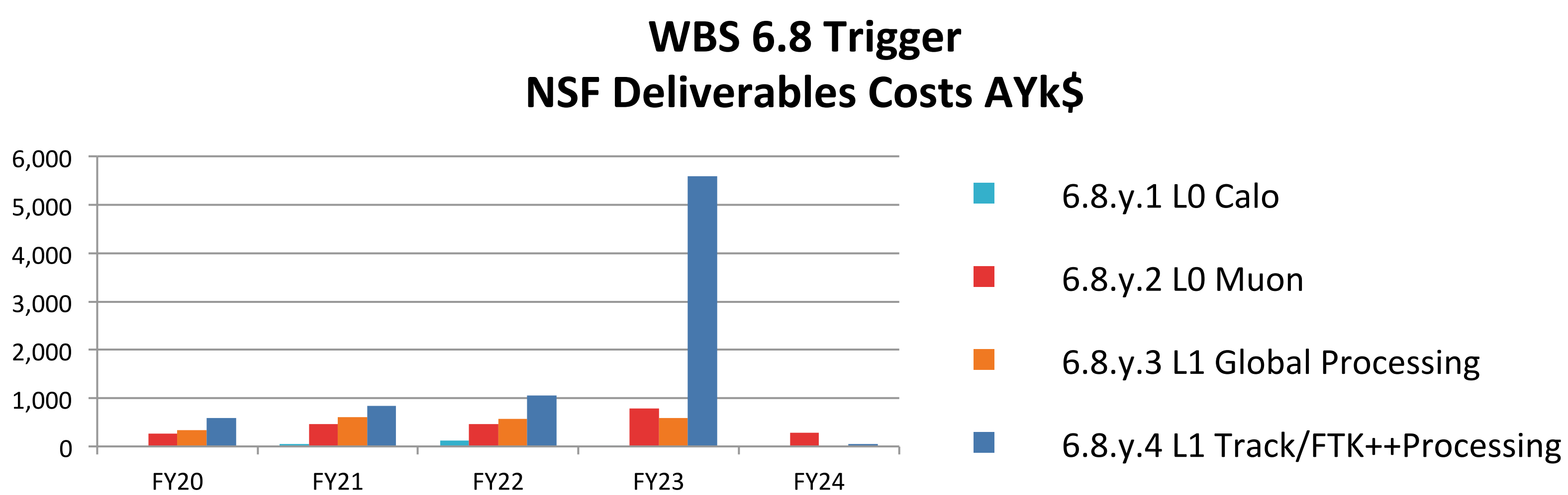


WBS 6.8 Trigger L2 NSF Resource Breakdown



Budget

6.8 Trigger NSF Total Cost (AYk$)						
Item/Phase	FY20	FY21	FY22	FY23	FY24	Total
6.8.y.1 L0 Calo	0	43	126	19	0	187
6.8.y.2 L0 Muon	265	455	466	778	291	2,256
6.8.y.3 L1 Global Processing	337	611	569	586	0	2,103
6.8.y.4 L1 Track/FTK++Processing	594	835	1,054	5,598	51	8,132
NSF Grand Total	1,197	1,943	2,215	6,980	343	12,678



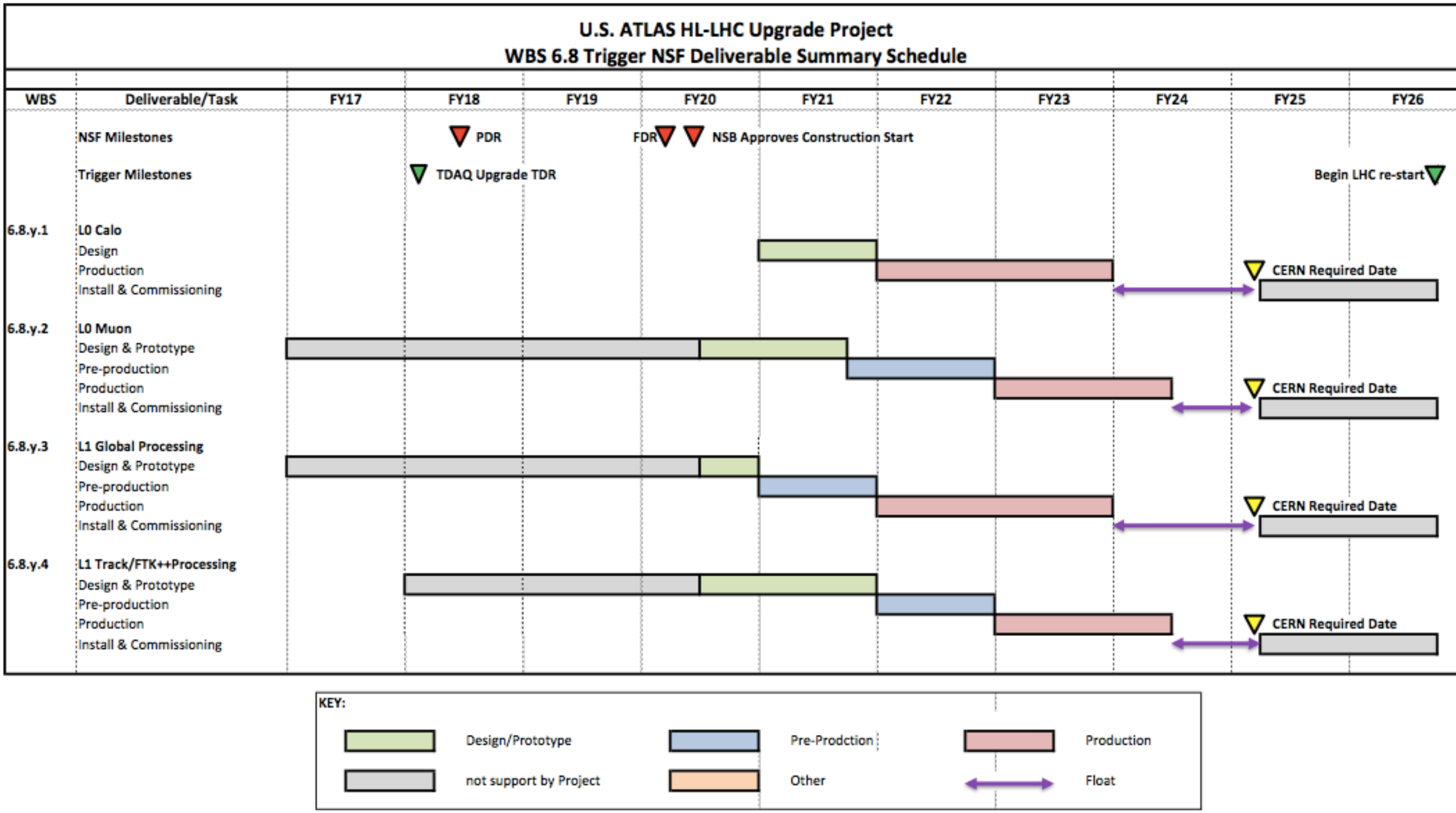
Effort Details

6.8 Trigger NSF FTEs by Labor Types						
Item/Phase	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**Total**
6.8.y.1 L0 Calo	**-**	**0.25**	**0.42**	**0.08**	**-**	**0.75**
Engineer	-	0.25	0.42	0.08	-	0.75
Technician	-	-	-	-	-	-
Student	-	-	-	-	-	-
6.8.y.2 L0 Muon	**1.50**	**2.75**	**2.75**	**2.75**	**2.06**	**11.81**
Engineer	1.00	1.75	1.00	0.75	0.56	5.06
Technician	-	-	0.75	1.00	0.75	2.50
Student	0.50	1.00	1.00	1.00	0.75	4.25
6.8.y.3 L1 Global Processing	**1.25**	**2.50**	**2.50**	**2.50**	**-**	**8.75**
Engineer	1.25	2.50	2.50	2.50	-	8.75
Technician	-	-	-	-	-	-
Student	-	-	-	-	-	-
6.8.y.4 L1 Track/FTK++Processing	**2.50**	**4.00**	**2.00**	**1.75**	**0.25**	**10.50**
Main Board	**1.25**	**2.00**	**1.00**	**1.00**	**-**	**5.25**
Engineer	1.00	1.75	0.75	0.75	-	4.25
Technician	0.25	0.25	0.25	0.25	-	1.00
Student	-	-	-	-	-	-
Mezzanine	**1.25**	**2.00**	**1.00**	**0.75**	**0.25**	**5.25**
Engineer	1.00	1.75	0.75	0.58	0.17	4.25
Technician	0.25	0.25	0.25	0.17	0.08	1.00
Student	-	-	-	-	-	-
NSF Grand Total	**5.25**	**9.50**	**7.67**	**7.08**	**2.31**	**31.81**
Engineer	4.25	8.00	5.42	4.67	0.73	23.06
Technician	0.50	0.50	1.25	1.42	0.83	4.50
Student	0.50	1.00	1.00	1.00	0.75	4.25

Budget Details

6.8 Trigger NSF Total Cost (AYk$)						
Item/Phase	FY20	FY21	FY22	FY23	FY24	Total
6.8.y.1 L0 Calo	**0**	**43**	**126**	**19**	**0**	**187**
Design	0	43	0	0	0	43
Prototype	0	0	0	0	0	0
Pre-production	0	0	0	0	0	0
Production	0	0	126	19	0	144
6.8.y.2 L0 Muon	**265**	**455**	**466**	**778**	**291**	**2,256**
Design & Prototype	265	361	0	0	0	627
Pre-production	0	94	466	0	0	560
Production	0	0	0	778	291	1,069
6.8.y.3 L1 Global Processing	**337**	**611**	**569**	**586**	**0**	**2,103**
Design	0	0	0	0	0	0
Prototype	337	0	0	0	0	337
Pre-production	0	611	0	0	0	611
Production	0	0	569	586	0	1,155
6.8.y.4 L1 Track/FTK++Processing	**594**	**835**	**1,054**	**5,598**	**51**	**8,132**
Main Board	**297**	**417**	**628**	**3,479**	**0**	**4,821**
Design	0	0	0	0	0	0
Prototype	297	417	0	0	0	714
Pre-production	0	0	628	0	0	628
Production	0	0	0	3,479	0	3,479
Mezzanine	**297**	**417**	**427**	**2,119**	**51**	**3,311**
Design	0	0	0	0	0	0
Prototype	297	417	0	0	0	714
Pre-production	0	0	427	0	0	427
Production	0	0	0	2,119	51	2,170
NSF Grand Total	**1,197**	**1,943**	**2,215**	**6,980**	**343**	**12,678**

Schedule



U.S. ATLAS HL-LHC Upgrade Project
WBS 6.8 Trigger NSF Deliverable Summary Schedule
WBS
Deliverable/Task
FY17
FY18
FY19
FY20
FY21
FY22
FY23
FY24
FY25
FY26
NSF Milestones
PDR
FDR
NSB Approves Construction Start
Trigger Milestones
TDAQ Upgrade TDR
Begin LHC re-start
6.8.y.1
L0 Calo
Design
Production
Install & Commissioning
CERN Required Date
6.8.y.2
L0 Muon
Design & Prototype
Pre-production
Production
Install & Commissioning
CERN Required Date
6.8.y.3
L1 Global Processing
Design & Prototype
Pre-production
Production
Install & Commissioning
CERN Required Date
6.8.y.4
L1 Track/FTK++Processing
Design & Prototype
Pre-production
Production
Install & Commissioning
CERN Required Date
KEY:
Design/Prototype
Pre-Prodction
Production
not support by Project
Other
Float

External Dependencies

- 6.8.x.1 L0 Calo
  - Tile Calorimeter channel maps
- 6.8.x.2 L0 Muon
  - Carrier card that interfaces with the US Mezzanine board
- 6.8.x.3 L1 Global
  - Event Processor selection
- 6.8.x.4 L1Track/FTK++
  - Rear Transition Module (DOE deliverable) not available integrated testing
  - Non-US 1st mezzanine not available for testing

Risks

- General sources of risk
  - Changes or delays in system definition
  - Changes or delays in interfaces with other sub-systems
  - Performance of available FPGAs or other processors different than expected
- Mitigation
  - In general, mitigation is system specific
  - In some cases, development can continue even when system definitions are not complete
  - Performance issues can be handled by reducing target efficiencies if necessary

Budget Contingency

Budget Contingency

- Materials
  - 50% contingency
  - Rule applied: 40-60% for items with a detailed conceptual level of design and items adapted from existing designs but with extensive modifications.
- Labor
  - 50% contingency
  - Rule applied: 30-50% for a task that is not yet completely defined, but is analogous to past activities

Scope Contingency

Scope Contingency

- Early Decision ~ FY20
  - Remove one L1 Global algorithm -$380k
  - ATLAS management finds non-US replacement or some selection is not refined in L1 Global (end up raising a threshold)
- Late Decision ~ FY22
  - 30% instead of 50% L1Track/FTK++ mainboards $-1140k
  - ATLAS management finds non-US replacement or the efficiency/coverage will be reduced

Scope Opportunity

- Early Decision ~ FY20
  - add one L1 Global algorithm +$380k

System Engineering

- We have appointed Brandon Kunkler as the US ATLAS HL-LHC Trigger and DAQ integration engineer
  - Brandon worked on Belle II trigger system and electronics for several nuclear physics experiments
  - This task encompasses both the NSF trigger scope and the DOE DAQ/Data-handling scope
- The Trigger and DAQ systems have many internal interfaces as well as interfaces all detector subsystems
  - Will coordinate between NSF and DOE scope as well as with international ATLAS
  - Some key interfaces:
    - L1Track/FTK++ has interface between RTM and Mainboard, Mainboard and mezzanines
    - L0Muon has interface between Mezzanine and mainboard
    - L1Global Algorithms must run in selected hardware and interface to the rest of the firmware package
    - L0 Calo fiber plant interfaces with Tile Cal outputs and Phase-1 FEX inputs

Closing Remarks

- US Deliverables = List of BoEs
  - 6.8.y.1 L0 Calo fiber optic plant for new tile output
  - 6.8.y.2 L0 Muon MDT segment finding and fitting mezzanine
  - 6.8.y.3 L1 Global Processing algorithms for hadronic objects
  - 6.8.y.4 L1Track/FTK++ mainboard and second stage fitting mezzanines

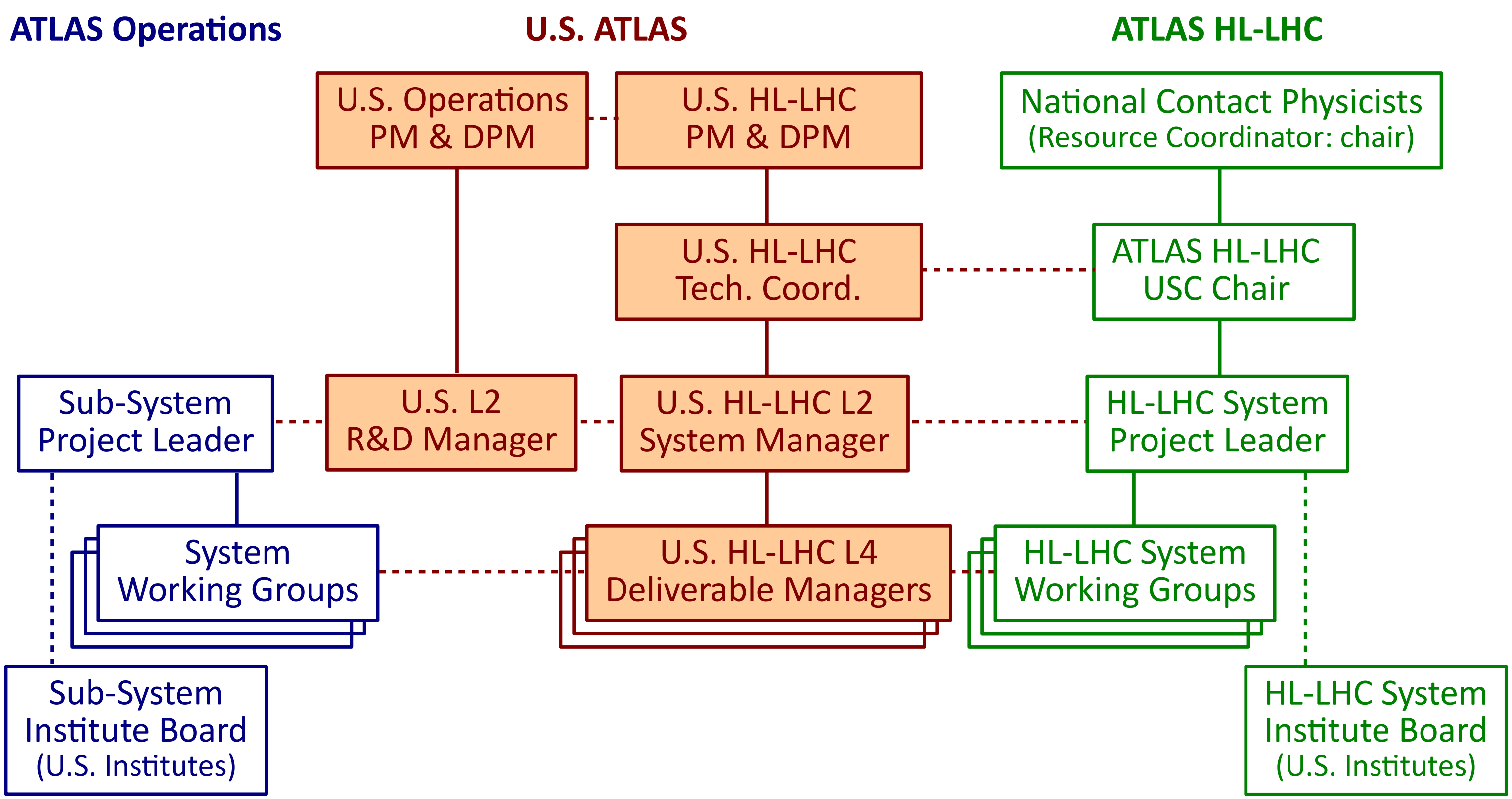
- This package with have a high impact on the ability of ATLAS to maintain low threshold single lepton and hadronic triggers

- Budget and Planning are based on Phase-1 experience

- Total budget for this L2 (no contingency): : $12,510k

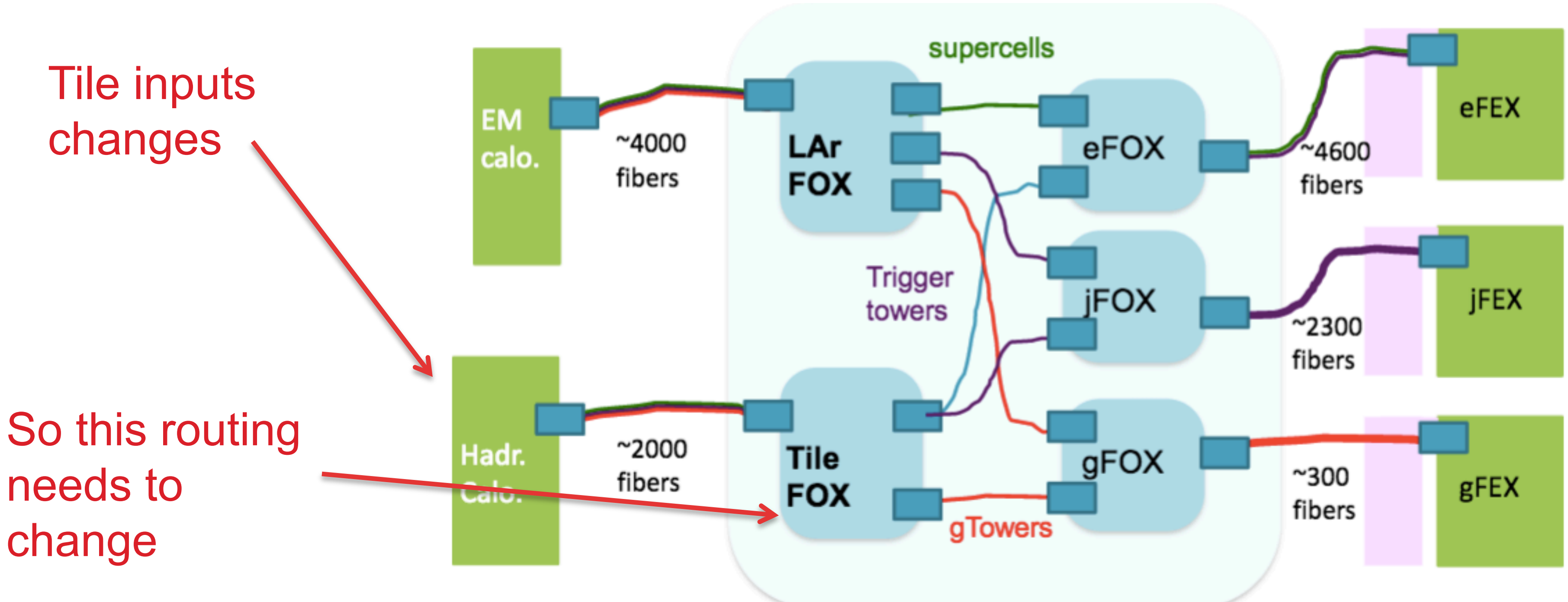
Backup

ATLAS Structure



6.8.y.1: L0 Calo Fiber Optic Plant

- Rebuild the Phase-1 Fiber Optic plant to accommodate the change to the tile electronics
- Builds on unique MSU experience with fiber routing and splitting

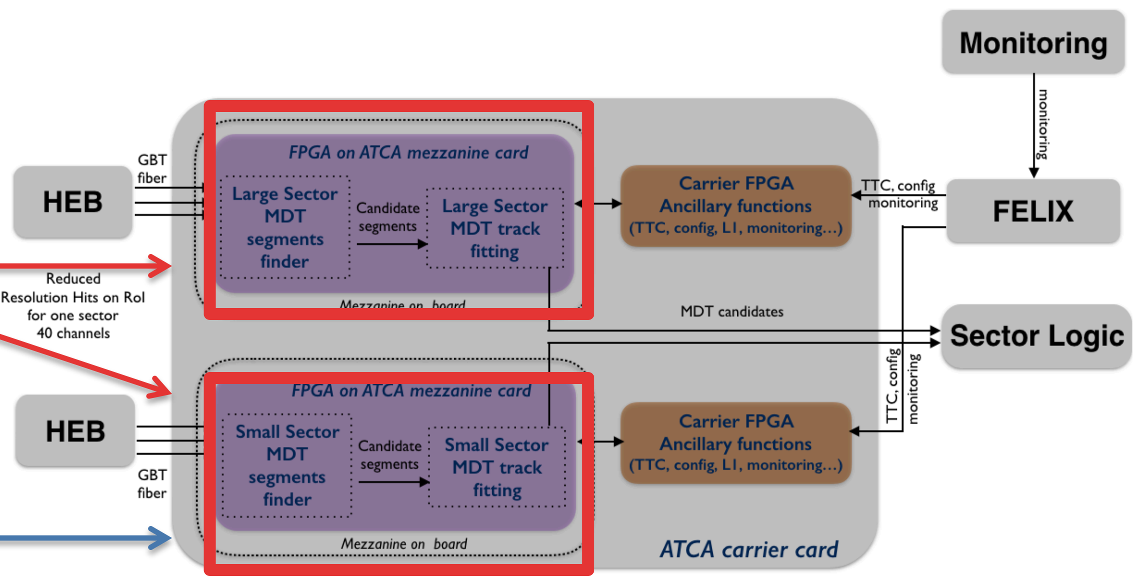


6.8.y.2: L0 Muon

- Deliverable is a mezzanine card with firmware that sits on a carrier card that handles the I/O with the system
  - Mezzanine find track segments, links them, and fits tracks
  - Contributes to muon rate reduction and efficiency improvement

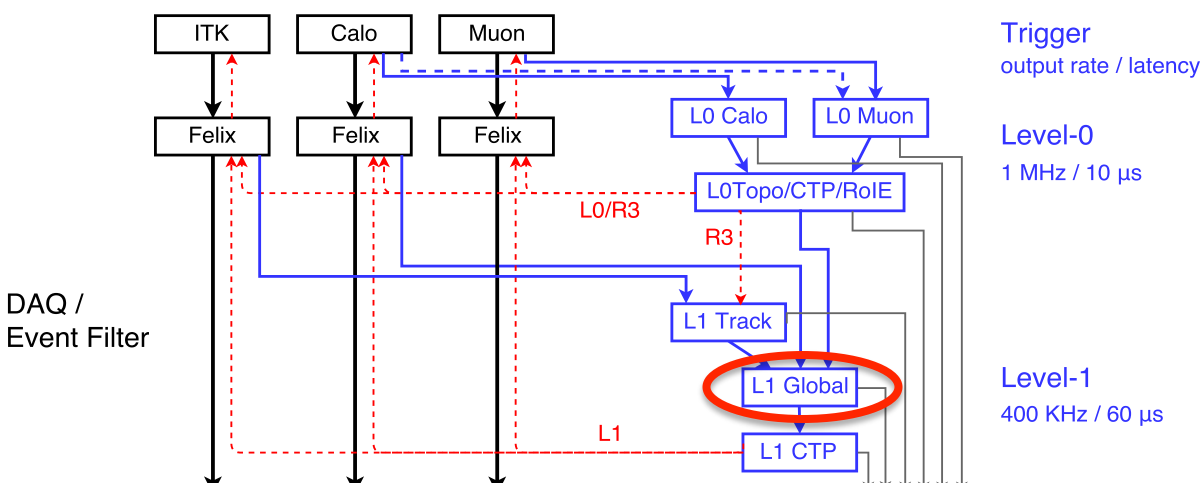
These are the mezzanines

They sit on a carrier card (non-US) which handles data routing



6.8.y.3: L1 Global Processing

- Deliverable is firmware that runs on the L1 Global Processor
  - The focus is on hadronic triggering with 4 related items
    - Offline-like "topological clustering" of calorimeter energy
    - Offline-like jet finding
    - Global quantities: Missing energy, sum of jet pTs (HT), and MHT
    - Track-based pile-up rejection for multijet and global quantities
- Follows Phase-1 experience with the gFEX system
  - gFEX is global quantities and fat-jets at what will be L0 in HL-LHC



6.8.y.4: L1Track/FTK++ processing

- L1Track/FTK++
  - L1Track provides regional tracking at 1 MHz at low-latency as input to L1 Global
    - Many many uses… key for electron, tau, and multiobject hadronic triggers
  - FTK++ provides full detector tracking to be used in the Event Filter (PC farm)
    - This is expected to be critical for maintaining sharp turn-on curves for offline definitions of jets and MET than involve tracking
- The L1Track/FTK++ systems are expected to use the same hardware with minor modifications
- Each system consists of two stages:
  - pattern recognition step with a preliminary track fit
  - second track fitting stage to include additional hits not used in pattern recognition
- Both stages are expect to use the same mainboard for data preparation
- Each stage will have its own mezzanine
- Deliverables are
  - Mainboard design and firmware (50% of hardware)
  - 100% Second-stage hardware and firmware

Quality Assurance Plans

Definition of Successful End of Project

- 6.8.y.1 L0 Calo
  - Delivery of assembled and tested system
- 6.8.y.2 L0 Muon
  - Delivery to CERN of 32 AMCs which have been tested with the carrier boards
- 6.8.y.3 L1 Global Processing
  - Completion functional algorithms with adequate demonstrated performance, resource consumption and timing
- 6.8.y.4 L1Track/FTK++
  - Delivery of boards to CERN with firmware that is ready for an full integration test (slice test will be a year early)